AUBE '01

12TH INTERNATIONAL CONFERENCE ON AUTOMATIC FIRE DETECTION

March 25 - 28, 2001
National Institute Of'Standards arid Technology
Gaithersburg, Maryland U.S.A.

PROCEEDINGS

Editors: Kellie Beall, William Grosshandler and Heinz Luck

NIST CENTENNIAL 1901-2001

EUSAS

NIST
National Institute of Standards and Technology
Technology Administration, U.S Department of Commerce

Thomas Cleary, Michelle Donnelly, and William Grosshandler
Building and Fire Research Laboratory, National Institute of Standards and Technology
Gaithersburg, MD, 20899 U.S.A.

The Fire Emulator/Detector Evaluator: Design, Operation, and Performance

1. Introduction

Grosshandler introduced the concept of a "universal fire emulator/detector evaluator" (FEDE) at *AUBE '95*, and development of such an apparatus began at NIST soon thereafter [1]. The FEDE has proven to be a very flexible design. The main function of the device is to reproduce the environment (temperature, air velocity, aerosol and gas species concentrations) a detector would be exposed to during fire and non-fire events. It has been used primarily for fire detection, but may prove useful in testing other types of sensors such as those used for indoor air quality assessment, building HVAC control, or hazardous gas monitoring. The FEDE is a single-pass "wind tunnel" that allows for the control of the flow velocity, air temperature, gas species, and aerosol concentrations at a test section wherein detectors and sensors are exposed to these environmental conditions.

While others have developed tunnels to test specific aspects of fire detector performance, the FEDE is the only apparatus designed to reproduce all relevant conditions needed to assess the performance of spot-type particulate, thermal and gas sensor detectors or combination detectors. It has been used in a study of the smoke entry lag of commercial analog-output photoelectric and ionization detectors, where a two-parameter model was developed that allows for the prediction of the analog detector response given smoke concentration and velocity at the detector opening as a function of time [2]. It was used to emulate the smoke temperature and flow velocity conditions developed in a modeled detector sensitivity room fire test [3]. Experimental results of analog-output detector response to test smoke from a propene soot generator, oil aerosol from a smoke detector testing device, and aerosolized Arizona test dust were presented at *AUBE '99* [4]. Recent work at NIST that utilized the FEDE is described in several papers presented at this conference: ***AUBE '01*** (see other papers in this proceedings). Below is a description of the FEDE hardware, performance range, and selected experimental results.

2. Experimental Apparatus

A schematic of the FEDE is shown in Figure 1. Room air is drawn into the opening, and exhausted to a hood at the end of the duct. The air velocity at the test section is controlled over a range of flows between **0.02** m/s to over **2** m/s by means of the computer-controlled axial blower. Air is first propelled through the annular finned heating elements, then travels along the duct to the test section. The flow is conditioned before it reaches the test section by passing through a 10 cm long aluminum honeycomb with ***5*** mm rectangular openings. The goal is to provide a nominally flat flow profile indicative of what would be experienced by a detector in a ceiling jet flow. The flow is monitored at the test section by a thermo-anemometer capable of recording flows as low as 0.05 m/s with a stated uncertainty of 4 % of the reading. For lower velocities, or non-isothermal flows, other means must be employed such as pitot probes, hot-wire anemometry, or laser doppler velocimetry. Figure **2** shows the mean centerline axial velocity as a function of distance from the top of the duct for a range of fan speeds. The flow profile is nearly top-hat, and at each stationary position the velocity fluctuates indicating turbulent flow. The horizontal bars indicate a two standard deviation range in the mean velocity measured by the thermo-anemometer. Transition from laminar to turbulent flow is expected at velocities above **0.08** m/s based on the duct Reynolds number. Heat is added to the flow by a series of **9** annular finned heating elements. Each element is rated at ***5*** kW for a total maximum heat input of 45 kW. Power to the heating elements is controlled by a feedback controller that receives set-point values from a computer file and compares them to the air temperature exiting the heaters. (An air temperature difference between the heater exit and test section location is due to heat losses to the duct section between those two points. Therefore, it is not practical to use the test section temperature for feedback control.) A rate of temperature rise in air flow of 0.5 **°C/s** is achievable at the test section, up to maximum of about **80** °C. Air temperatures and duct wall temperatures are recorded at the test section with type-K thermocouples. Figure **3** shows the air temperature response to a programmed sequence

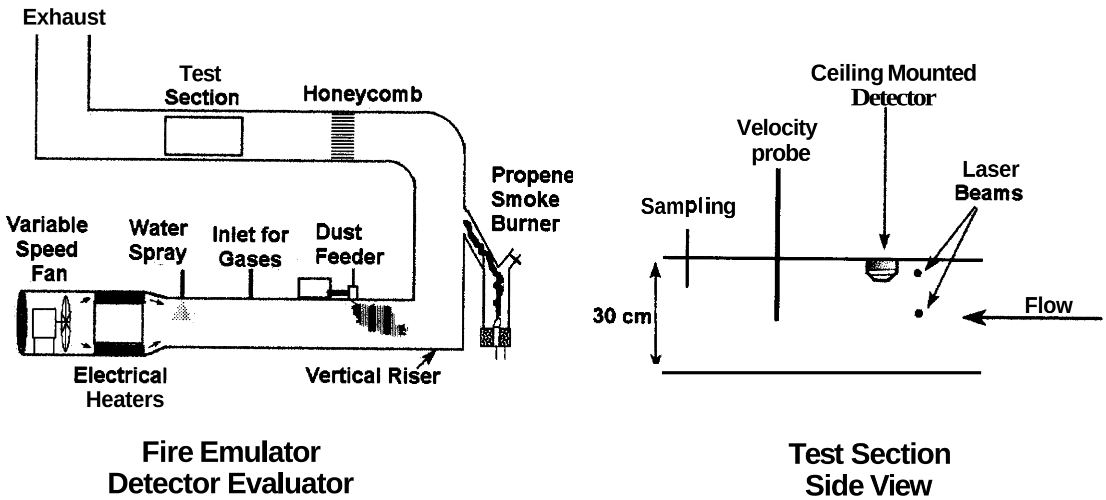

Figure 1. Schematic of the fire emulator/detector evaluator.

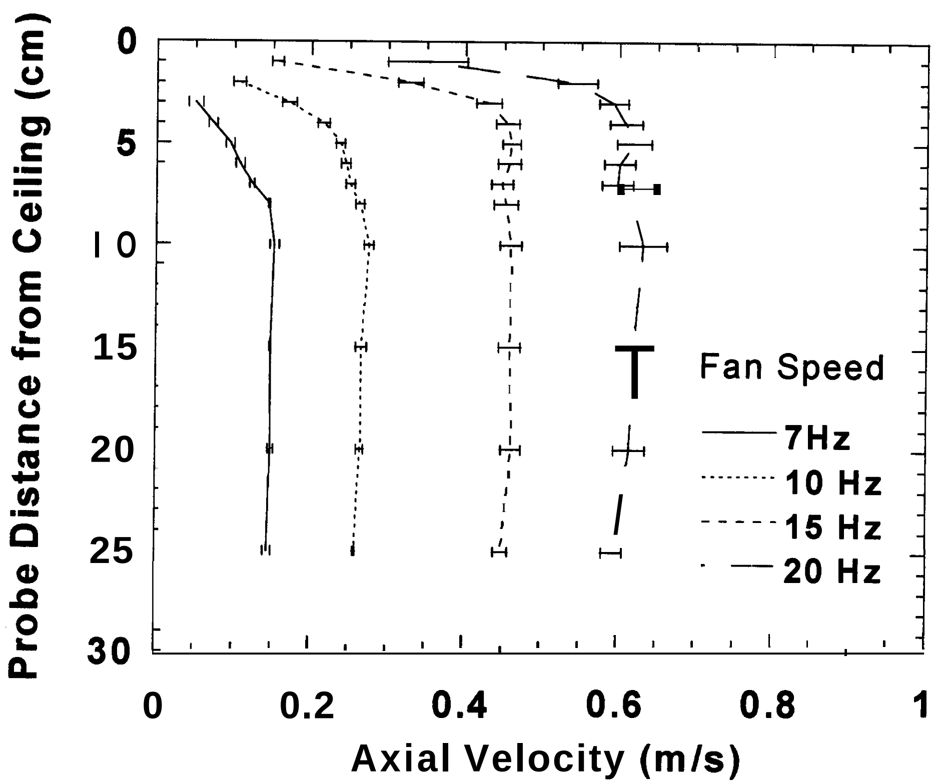

Figure 2. Axial velocity at the duct centerline as a function of distance from the ceiling.

of temperature set point values sent to the heater controller, and fan speed settings. This sequence was designed to reproduce velocity and air temperature rise at a detector location predicted from a modeled test fire (the particular example is for location 11 described in reference *[5]* found in these proceedings). The graph shows the air temperature for four repeated runs, along with the heater set point values. Figure **4** shows the flow velocity at the duct center at the test section for these repeated runs along with the fan speed settings.

CO, CO_2, or other gas blends may be metered into the flow via electronic **mass** flow controllers. Superheated water may be sprayed into the flow after the heater section to fix humidity between ambient room and saturation conditions depending on the spray flow. Water, CO, CO_2, and hydrocarbon gas concentrations at the test section are monitored by non-dispersive infrared (NDIR) analyzers. The ability to control gas concentrations independently benefits both fire and nuisance alarm scenario emulation. For example, both CO and CO_2 may be normally present in ever-changing concentrations in a building due to the external environmental sources such as attached parking garages, or internal sources such as the diurnal CO_2 variation due to occupancy and ventilation levels.

Various types of smokes and non-combustion aerosols may be introduced into the flow, including flaming soot, smolder smokes, dust, nebulized liquid mists, and cooking aerosols. Laser light transmission measurements across the duct at the test section are used to calculate the light extinction coefficient or optical density of the aerosol. Extinction coefficient or optical density is the typical "concentration" measurement of smoke or other non-fire aerosol. **A** HeNe laser at **632.8** nm wavelength is the light source, and a stabilizer utilizing a liquid crystal polarizer maintains a nearly constant laser intensity. The beam is split and introduced at two heights: the center of the duct, and ***5*** cm below the ceiling. Each light beam is reflected off two mirrors inside the duct and directed at a photodetector placed on the opposite side of where the beam enters the duct. The total light transmission path length inside the duct is 1.5 m. The photodetector output voltage is linear with respect to the transmitted light intensity. The standard relative uncertainty due to random fluctuations in the output is **0.06** % of the

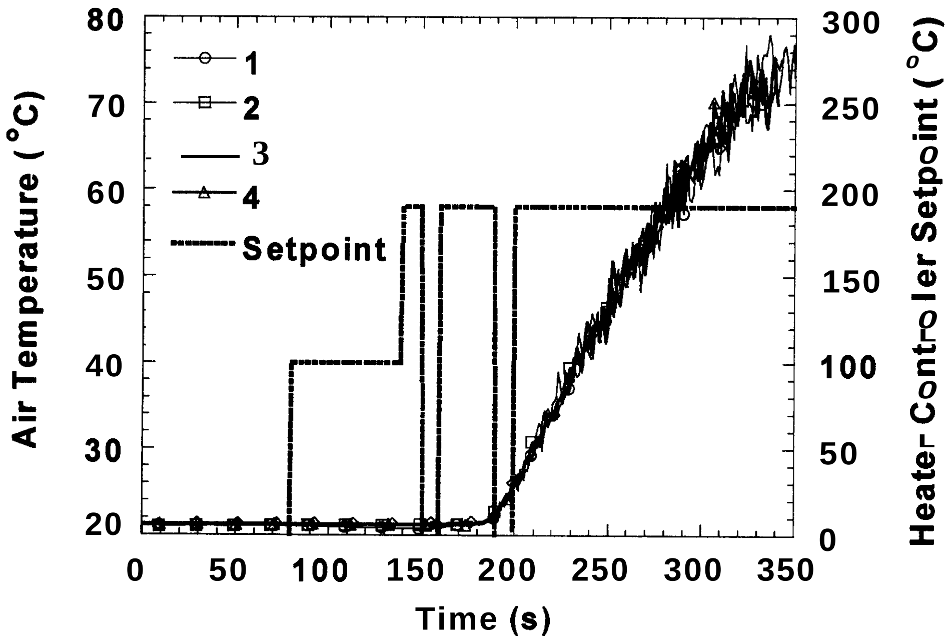

Figure 3. Temperature at a detector location for repeated emulations of a modeled fire.

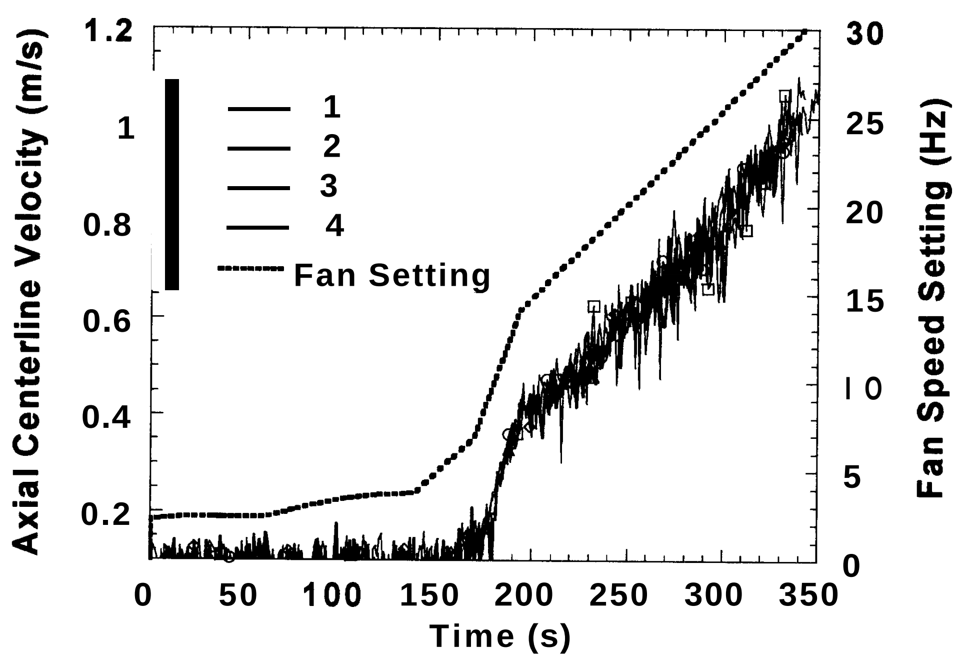

Figure 4. Velocity at a detector location for repeated emulations of a modeled fire.

measured light transmittance (light intensity divided by smoke-free initial light intensity). The extinction coefficient is computed by dividing the natural logarithm of the transmittance by the path length through the smoke and multiplying by (-1). A measuring ionization chamber (MIC) can be located in the test section to provide a reference chamber current measurement more appropriate for ionization detectors than light extinction.

3. Smoke Aerosols

The flaming and smoldering smokes produced cover a wide range of physical properties and concentrations. The propene smoke generator provides black soot typical of flaming hydrocarbon or plastics fire smoke. The generator is directly attached to the FEDE duct at the vertical riser section. The concentration of smoke in the flow is varied by changing the fuel flow of the burner, and opening or closing dampers allowing more or less flow from the burner to enter the duct. Examples of emulated flaming fire conditions are given in references [5,6] in these proceedings. Propene smoke generated in the FEDE was collected for the light scattering study in reference [7]. A steady concentration of smoke was provided at the test section (fan speed set at 7 Hz), then collected for light scattering experiments. Figure 5 shows the light transmittance of the upper laser beam traversing the test section and the MIC current output. Here, data gathering began after steady conditions were achieved, as indicated by the transmittance and MIC output. The smoke collection time for the smoke used in the light scattering experiment was from 30 s to 390 s.

Pyrolyzing wood smoke was generated by heating 8 beech wood blocks, 3.5 cm x 2.0 cm x 1.0 cm on an electric hotplate placed inside the duct at the bottom of the vertical riser (Figure 6). This scenario is similar to the fire sensitivity test fire 2 in EN 54 part 9 [8]. The hotplate was operated at full power for this test (750 kW), and the fan speed was set to 7 Hz. For this test the hotplate was turned on at 30 s and turned off at 1300 s. Smoke generated from the heated wood blocks was also collected and studied in the light scattering and size distribution experiments described in [7]. Figure 7 shows the light transmittance of the upper laser beam traversing the test section and the MIC current output for this scenario. The MIC output started to drop at approximately 550 s while the

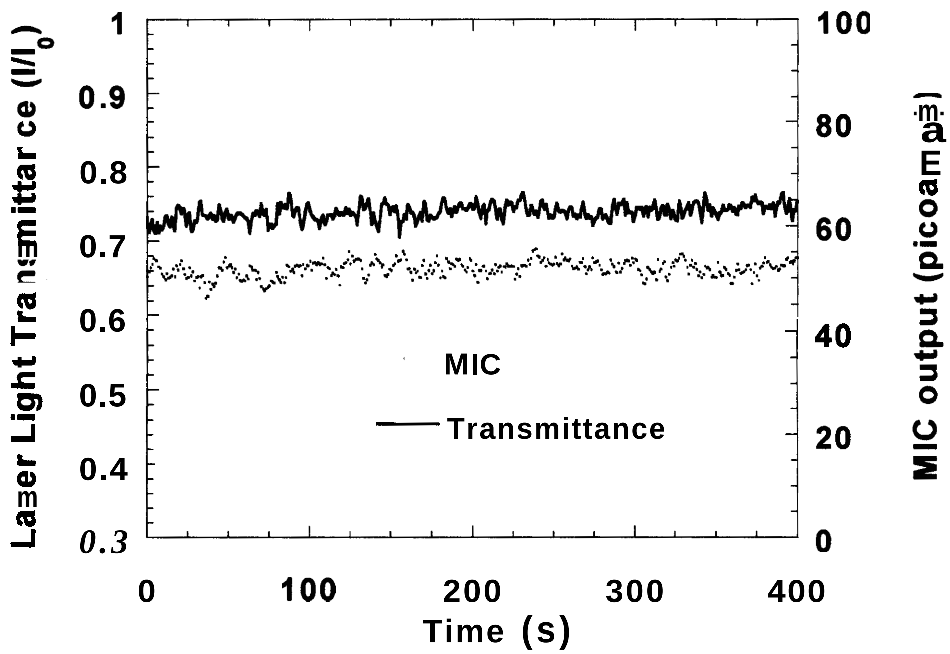

Figure **5.** Transmittance and MIC output for steady propene smoke concentration.

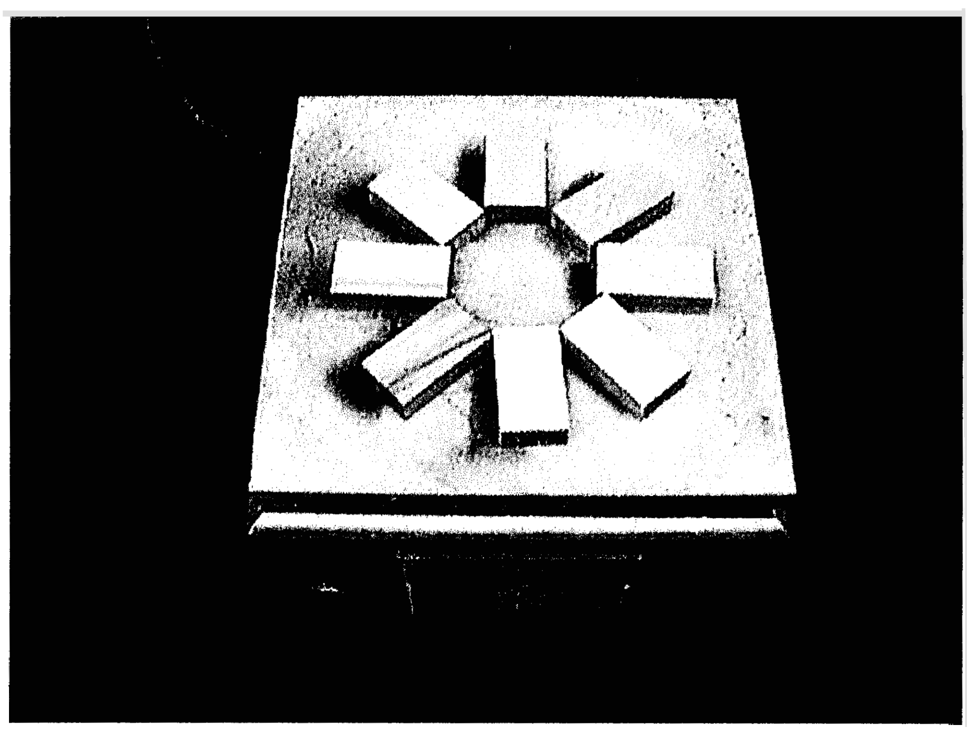

Figure **6.** Electric hotplate with arranged wood blocks prior to testing.

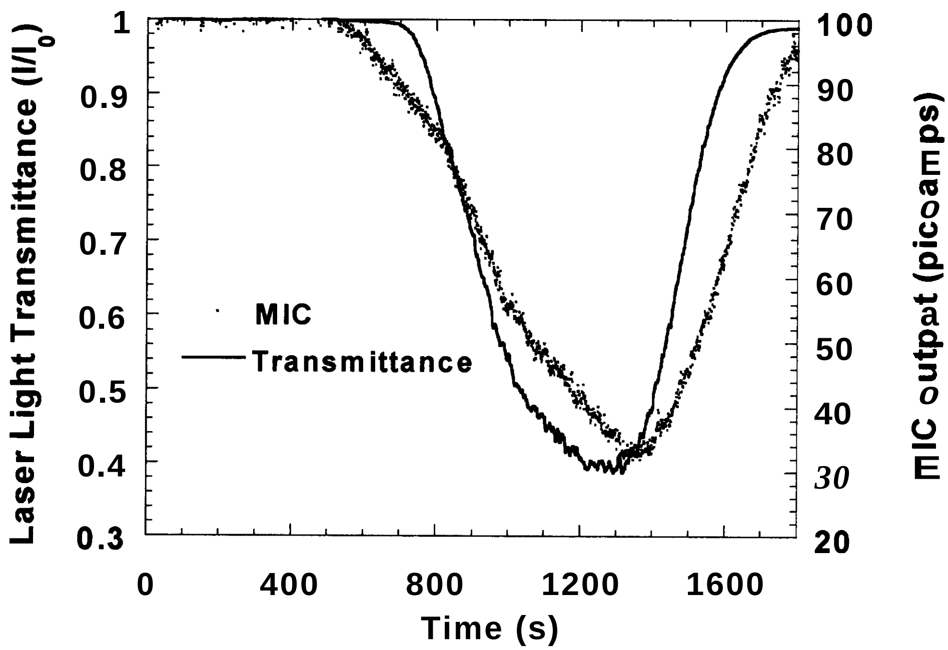

Figure **7.** Transmittance and **MIC** output for pyrolyzing wood blocks source.

transmittance began to drop around 700 **s,** and both were continuously changing throughout the test. Smoke for the light scattering and size distribution measurements was collected over a time period from **800 s** to **1160 s.** Over this collection period, the transmittance dropped from **0.9** to **0.4.**

Smoldering cotton smoke is generated by a staged-wick-ignition device (Figure **8)** that ignites wicks by applying power to electrical heating wires in a prescribed computer-controlled sequence to affect a specific rate of smoke build-up at the test section. Eight groups of up to four individual wicks can be ignited in sequence to provide the controlled rate-of-rise in smoke concentration at the test section. The cotton smolder source is similar to the cotton smolder test fire 3 in EN **54** part **9** [8]. Smoke generated from the smoldering wicks was also collected and studied in the light scattering and size distribution experiments described in [7]. Successive application of power to each of the eight sets of four wick igniters was performed at 12 **s** intervals to achieve the smoke buildup; data collection began **30 s** prior to the start of the ignition sequence. Figure **9**

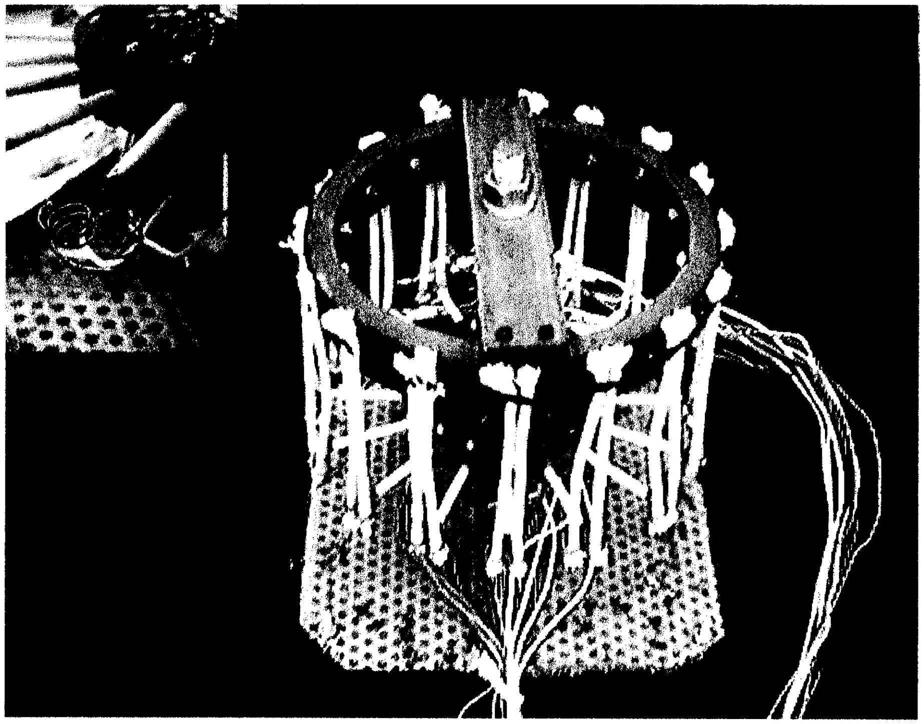

Figure 8. Staged-wick ignition device with close-up of an igniter.

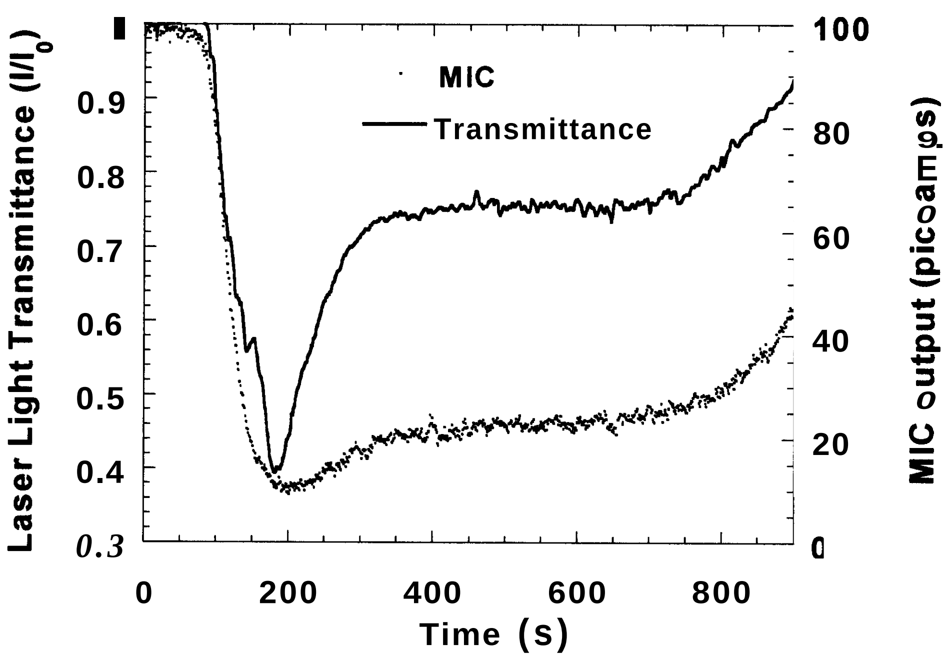

Figure 9. Transmittance and MIC output for cotton smolder smoke.

shows the shows the light transmittance of the upper laser beam traversing the test section and the MIC current output for this scenario. The transmittance and MIC current initially drop at the same rate. It then appears that the MIC output looses sensitivity at a light transmittance below **0.6.** At about **190** s, the transmittance reached its lowest value. All **32** wicks have ignited and each are approaching the steady burning rate period. Between **350** s to **750** s the wicks burn at a steady rate **as** evidenced by the transmittance and MIC output values. After **750** s the first set of four wicks start to burn out, followed by successive groups of four later. Smoke for the light scattering and size distribution measurements in **[7]** were collected over a time period from **360** s to **720** s.

An illustration of the relative difference in the properties of these test smokes as related to the response of light scattering and ionization detectors is shown in Figure 10 where the ratio of the normalized MIC output ($(I_0-I)/I_0$ where I_0 is the initial chamber current and I is the present value of the chamber current) to extinction coefficient over the collection times for each of the smokes is plotted. The ratio is steady for cotton smolder

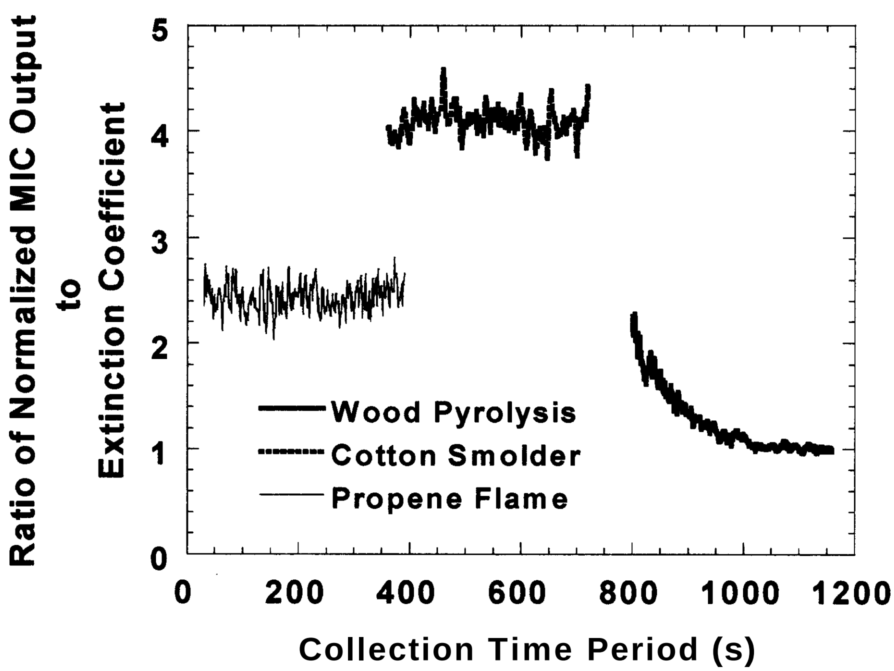

Figure 10. Ratio of normalized MIC output to extinction coefficient for FFE/DE test smokes collected for light scattering and size distribution measurements.

and propene smoke with means of 4.2 and 2.5 respectively, following a collection time period when the extinction coefficient was a constant value of $0.2\ m^{-1}$ in both cases. The ratio computed for the wood smoke varied from about 2 to 1 over the collection time period. The ratio for wood smoke during the brief collection time when the extinction coefficient was $0.2\ m^{-1}$ was 1.3. Comparing the two non-flaming smokes, the ratio is 3.2 times higher for the cotton smoke at that fixed extinction coefficient. This implies that at a fixed concentration, an ionization sensor will be more sensitive to cotton smoke compared to the wood smoke. The size distribution measurements in reference [7] offer an explanation for this effect based on the observation that the cotton smoke size distribution is shifted to smaller particle size compared to wood smoke. More work is planned to characterize other fire smokes and nuisance aerosols produced in the FE/DE

4. Conclusions

The FE/DE is capable of emulating a wide range of fire and non-fire environments to which a spot-type detector could be exposed. Air flows, temperatures, smoke and combustion gas concentrations from growing fires can be emulated accurately in the FE/DE up to levels where detectors should alarm. The flaming and non-flaming fire smokes generated cover a range of concentrations and physical properties that impact smoke detector response.

5. References

[1] Grosshandler, W.L., "Toward the Development of a Universal Fire Emulator/ Detector Evaluator," Fire Safety Journal 29, 113-128, (1997).; also in AUBE '95 Proceedings, pp. 368-380.

[2] Cleary, T., Chernovsky, A., Grosshandler, W., and Anderson, M., "Particulate Entry Lag in Spot-Type Smoke Detectors," Sixth International Symposium on Fire Safety Science, University of Poitiers, France, July, 1999.

[3] Cleary, T., Anderson, M., Averill, J., and Grosshandler, W., "Evaluating Multi-sensor Fire Detectors in the Fire Emulator/Detector Evaluator," Proceedings of the 8th Inter. Conf. on Fire Science and Eng., Interflam '99, Edinburg, Scotland, June 1999.

[4] Cleary, T., Grosshandler, W., and Chernovsky, A., "Smoke Detector Response to Nuisance Aerosols," Proceeding of the 11th International Conference on Automatic Fire Detection "AUBE '99", March 16-18, 1999, Gerhard Mercator University, Duisburg, Germany, Luck, H., Ed., pp 32-41, 1999.

[5] Cleary, T., Donnelly, M., Mulholland, G., and Farouk, B., "Fire Detector Performance Predictions in a Simulated Multi-room Configuration," Proceeding of the 12th International Conference on Automatic Fire Detection "AUBE '01", March 26-28, 2001, National Institute of Standards and Technology, Gaithersburg, MD, USA, Grosshandler, W., Ed., 2001.

[6] Cleary, T., and Donnelly, M., "Aircraft Cargo Compartment Fire and Nuisance Source Tests in the FE/DE," Proceeding of the 12th International Conference on Automatic Fire Detection "AUBE '01", March 26-28, 2001, National Institute of Standards and Technology, Gaithersburg, MD, USA, Grosshandler, W., Ed., 2001.

[7] Weinert, D., Cleary, T., and Mulholland, G., "Size Distribution and Light Scattering Properties of Test Smokes," Proceeding of the 12th International Conference on Automatic Fire Detection "AUBE '01", March 26-28, 2001, National Institute of Standards and Technology, Gaithersburg, MD, USA, Grosshandler, W., Ed., 2001.

[8] EN 54: Components of Automatic Fire Detection Systems, European Committee for Standardization, Parts 1-9, 1988